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Review of Single-Entry Longwall Mining Technology in the United States

By F. M. Jenkins and E. T. Cullen

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ILLUSTRATIONS

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

cfm	cubic foot per minute	mt	metric ton
ft	foot	pct	percent
ga	gauge	st	short ton
in	inch	V	volt
kV•A	kilovolt ampere		

REVIEW OF SINGLE-ENTRY LONGWALL MINING TECHNOLOGY IN THE UNITED STATES

By F. M. Jenkins[1] and E. T. Cullen[2]

ABSTRACT

Longwall mining systems are used to mine approximately 50 pct of the world's total underground coal production. Single entries are the predominant method of longwall development in Europe and Asia, where mining conditions are more severe than those encountered in the United States. During the 1970's and early 1980's, the U.S. Bureau of Mines and the U.S. mining industry invested nearly $20 million in single-entry and related research. This report reviews the accomplishments of single-entry research in the United States and describes two U.S. single-entry field projects: the Sunnyside single-entry project in central Utah and the tunnel-boring project in northern West Virginia. Also discussed are a single-entry study conducted by North American Mining Consultants (NAMCO) and a single-entry design study conducted by Ketron, Inc. This Bureau report compares the resulting technology with European counterparts to further assess the utility and efficiency of U.S. systems.

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INTRODUCTION

Underground coal mines in the United States have used room-and-pillar methods of extraction almost exclusively, first employing the drill, blast, and load cycle and later using continuous mining machines. The room-and-pillar method of driving several parallel entries still dominates the layout of most coal mines. U.S. mining regulations evolved from experience gained in room-and-pillar mining and the use of multiple entries. Therefore, underground coal mining methods that employ different entry configurations are constrained by regulations for room-and-pillar mining. For example, until the regulations were revised in 1988, longwall mining was defined by the Code of Federal Regulations (CFR) as a special case of room-and-pillar mining (30 CFR 75.201-3, 1987) and hence was subject to laws governing that method.

The U.S. coal industry currently mines underground seams where conditions are relatively favorable; that is, seams are thick, uniform, have few faults, and lie under fairly shallow cover. Under these conditions, room-and-pillar and longwall mining methods result in relatively high production rates and favorable economic conditions. As easily recovered supplies are exhausted, however, U.S. mine operators will be forced to mine reserves where conditions are more severe, requiring new mining techniques. This is the case in Europe where longwall mining with single-entry development evolved as a method of handling severe mining conditions.

Longwall mining was introduced into the United States as a means of increasing productivity. It was first tried at the turn of the century, but was abandoned because of the difficulty of manually moving timber support lines across the coal face. With the introduction of self-advancing mechanical props, longwall mining was tried again in Utah and West Virginia in the early 1960's. In Eastern U.S. coalfields, longwall mining was used in mines having ground control problems–ones with mudstone or friable shale roofs, which caved easily. Even though the cover was shallow, the mechanical props were too light, and these operations were not considered to be successful. Longwalls were then tried in seams with massive roof strata and shallow cover, again using light props. Under such conditions, the support either failed or was operated with great difficulty. As a result of these experiences, the growth of longwall mining in the East was stunted. At the same time, the Sunnyside Mines in Carbon County, UT, were among the first Western U.S. operations to use longwalls extensively in deep cover. These installations were successful; however, development-entry stability was a serious problem.

In 1966, two longwalls were again tried in the East, one at considerable depth, under massive sandstone roof strata. Both were equipped with heavy-duty mechanical supports. Both longwalls were instantly successful, leading to the first modest expansion of the longwall mining system in the late 1960's. Improvements in equipment and mining of thicker seams have accounted for dramatic increases in the productivity of longwall mining since 1980.

Longwall mining offers several advantages over room-and-pillar mining. Carrying one long face and allowing the roof to break and cave behind the face simplifies roof control and ventilation problems, allows recovery of a higher percentage of the coal, increases production, and provides safer working conditions (*1*).[3]

Stresses created under deep cover can cause ground control problems for longwall operations, however. Longwall operations at the Sunnyside Mines under 2,500 ft of overburden experienced stability problems in both headgate and tailgate entries. Extreme roof and floor convergence, bumps, and bursting of the chain pillars forced the Sunnyside Mines to use a two-entry system to develop longwall panels. The mine continued using two entries to develop longwall panels under a "grandfather" clause in the Federal Coal Mine Health and Safety Act of 1969 even though three entries were required by the act. In spite of the double-entry development system, bumps and sloughing of the roof and ribs continued to be problems. In an effort to solve these problems, the company proposed experimenting with a single-entry development system under a cooperative research project with the U.S. Bureau of Mines. This proposal was accepted, and the first U.S. single-entry project began in 1971.

In the same year, another cooperative research project was proposed to the Bureau by Eastern Associated Coal Corp. (EACC), Pittsburgh, PA, to drive a main development heading with a tunnel-boring machine (TBM). A TBM is a continuous excavation machine limited by its size and operation to excavating a single, circular-shaped entry. TBM's have been used worldwide for many years in such underground construction projects as transportation tunnels and watercourses. The TBM project, conducted from 1973 to 1979, had a purpose different from that of the Sunnyside project; however, both had an impact on single-entry research. Each project resulted in single entries being driven for development purposes. The TBM drove a main entry to reach a remote ventilation shaft, while the Sunnyside single entries developed production longwall panels. These two projects marked the beginning of single-entry research in the United States. By the first part of the 1980's, the coal industry and the Bureau had invested nearly $20 million in single-entry and related research.

The main objective of this report is to document U.S. experience in single-entry research. This work was done in support of the Bureau's mission to improve the health and safety of miners in underground coal mines and to increase the productivity of those mines. The review begins with a look at single-entry coal mine development abroad. Much can be learned by comparing the equipment, methods, and regulations of other countries that use single entries with those of the United States, primarily

[3]Italic numbers in parentheses refer to items in the list of references at the end of this report.

those used in the Sunnyside and TBM demonstrations. Both projects are reviewed to point out lessons learned from these experiences.

This report does not deal with single-entry methods applied to other coal mining situations in this country, such as advancing longwall operations (*2*) and slope developments (*3-4*). For example, in Mid-Continent Resources' L. S. Wood Mine in Pitkin County, CO, a single entry was developed as part of the longwall face. The entry was immediately separated into a double entry by a pumped pack wall and could be used as a panel for multilift longwall mining. The mining plan involved removing the top half of a 28-ft-thick coal seam with an advancing longwall and removing the remaining bottom half with a retreating longwall (*5*). Special situations such as this do not involve traditional in-seam single-entry excavations for coal reserve development.

Two other sources of information are important to U.S. single-entry research. The first is a U.S. Department of Energy (DOE) contract report entitled "Single-Entry Longwall Study" (*6*) in which NAMCO, New York, NY, compared the pertinent mining regulations of other coal-producing countries to those of the United States. The second is a study of the design of a single-entry development system for retreat longwall mining systems by Ketron, Inc., Wayne, PA. It employed a systems-design approach that improved the in-seam divided single-entry concept used at Sunnyside.

SINGLE-ENTRY TECHNOLOGY ABROAD

DEVELOPMENT

Longwall mining has been the rule rather than the exception for many years in the major coal-producing countries of Europe. This is a result of the conditions encountered as shallow coal reserves were exhausted and mining moved to deeper workings. European (which includes British) coalfields generally lie in thinner beds and at greater depths than U.S. deposits currently mined. Depths of 3,000 to 4,000 ft are common, and much greater ground pressures are experienced than in this country's coal mines.

In Europe, both advance and retreat longwall mining are practiced. In advance longwall mining, the entry or entries used to access the face may be driven with the face or ahead of the face. These entries must remain open throughout mining of the panel to provide haulage, ventilation, and escapeways. For retreat longwall mining, a coal block is defined by the complete driving of the entries before the face equipment is installed. The face is then mined back toward the haulage main, allowing the roof to cave behind. In either advance or retreat systems, if longwall panels are to be developed consecutively across a coal block, the entries will be used for two panels (headgate for one longwall and tailgate for the succeeding one). Therefore, the entries must be kept open for the time it takes to mine two complete longwall panels. Single-entry longwall development was a solution to the strata problems experienced in Europe (*6*).

European-type single entries are driven much as U.S. tunnels are driven, that is, undivided with mandatory auxiliary ventilation provided by intake or return air tubes or both. European mining regulations are much more stringent than U.S. regulations in some areas and less so in others. In Europe, <u>all</u> equipment in the single entry must be permissible and fireproof; however, only one escapeway is required. European law also restricts the number of miners working in the single entry, and fire protection measures tend to be more severe.

Europeans use single entries to develop retreating and advancing longwalls for a number of important reasons: (1) They offer complete extraction of limited coal reserves, (2) they provide a method of limiting subsidence damage at the surface, and (3) they offer superior control of extreme ground pressures at great depth. When a mine is deep, an entry developed in solid coal will not stay open without excessive support maintenance. This phenomenon appears when depth exceeds a specific limit, which depends on the nature of the strata, coal strength, and pressure concentrations resulting from prior mining. This type of structural instability should be distinguished from localized roof falls. These instabilities are, of course, interrelated; however, structural instability will not always result in roof falls, but rather may cause a gradual closure of the opening. Pillars will yield or the floor will heave, restricting movement through the entry. In many cases, single entries are driven completely away from the coal seam in more competent rock, which results in less closure in the longwall development openings.

Extreme rock pressure may also limit the use of retreating longwalls to cases where development entries remain usable throughout the life of the panel. When entries require excessive support maintenance, the primary consequences are that developments are made only as needed, not ahead of time, and the number of entries is kept to a minimum. The advantage inherent in driving a single entry comes from its geometric configuration. Stability is maintained because less ground is disturbed, chain pillars are not created, and the stress field of the surrounding area is uniformly distributed around the single opening. A secondary consequence is that when the total number of entries is kept to a minimum, more care can be given to supporting them. Wire mesh is bolted to the roof and walls, steel arches are set, and the cavity between the support and the stratum is filled. With this type of support, maintenance of a single entry is less time consuming and less costly than for a multiple-entry development.

There is a major difference between U.S. and European development philosophies. Generally, in Europe, entry development is considered a necessary, expensive investment to open longwall panels. Coal is not produced during development since either rock is taken with the coal

seam or the entry is driven entirely out of seam. This type of development is expensive, but in the long term, better returns on investment can be achieved. Very little coal must be left in place for support, and the maintenance of main entries is much less expensive because ground disturbance during development is minimal. A coal property can be developed from a central location to its boundaries and production can then proceed inward, leaving the mined-out area behind. In this way, all the advantages of single entries–that is, rapid development, improved extraction ratio, improved subsidence control, and improved ground control–can be realized. U.S. mines, on the other hand, view the development stage as a coal-producing unit in its own right and therefore as profit generating. This disparity between U.S. and European strategies promotes two entirely different development approaches and results in a marked dissimilarity in the number and configuration of entries in development headings.

Longwall panel development in the United States is carried out almost entirely in-seam, and multiple entries and crosscuts form rooms and pillars. European developments tend to be single entries driven out of seam with a large rectangular cross section or an arched roof if strata control is a problem. A width-height ratio of 3:2 is common (*6*). Haulage, ventilation, materials supply, and the escapeway are all contained in this one entry. Figure 1 shows a European-type single-entry development driven with a roadheader.

The absence of a divider wall is the most striking difference between U.S. and European single-entry systems. In order to drive the type of entry shown in figure 1, it is necessary to extract not only the coal, but a large amount of roof rock as well. Mining machines used to drive these entries must be able to cut rock as well as coal, and they must be permissible, a requirement placed on all equipment used in the entry. The main types used are roadheaders, dintheaders, in-seam miners, and continuous miners. The types of strata to be cut are the deciding factors in choosing which piece of equipment to use. Continuous miners are used for coal and soft rock, but roadheaders and dintheaders are preferred for harder strata. These machines also have the ability to drive arched or high rectangular entries, while continuous miners are somewhat limited as to the shape they can produce. Much research has gone into the design of these types of machines, and they are available in a variety of configurations to fill different mining needs.

One type of machine widely accepted and used in British mines is the partial cutting machine or in-seam miner. This type of machine drives a wide, low, elliptical entry and uses a continuous cutting operation. A discharge conveyor moves the cut coal from the back of the machine to the entry conveyor. The in-seam miner is used primarily in coal and soft rock and has the advantage of allowing immediate installation of supports while producing speeds of over 50 ft of advance per shift and generating little dust. Disadvantages are that it does not cut hard material efficiently and it is difficult to steer (*7*).

Longwall mining methods vary among the European coal-producing countries. British mine operators use more retreat mining, while West German mine operators favor advancing mining. In 1979, with over 400 operating longwall faces in the Federal Republic of Germany, 58 pct were advancing, primarily because retreat mining is more costly because of prior entry development. Retreat mining does, however, offer the advantages of reconnaissance of the coalbed prior to mining, cooling and degassing of the strata along the road, and separation of entry advance work from the face production with alleviation of the inherent dust problem. The West Germans take advantage of these benefits, yet still control costs by employing a ventilation system that allows one gate road to be developed prior to mining while the other is advanced with the face.

Another method that is becoming popular is the alternate advancing and retreating panels. Face equipment may be moved straight across the gate entry to the next panel, avoiding costly delays incurred while moving heavy

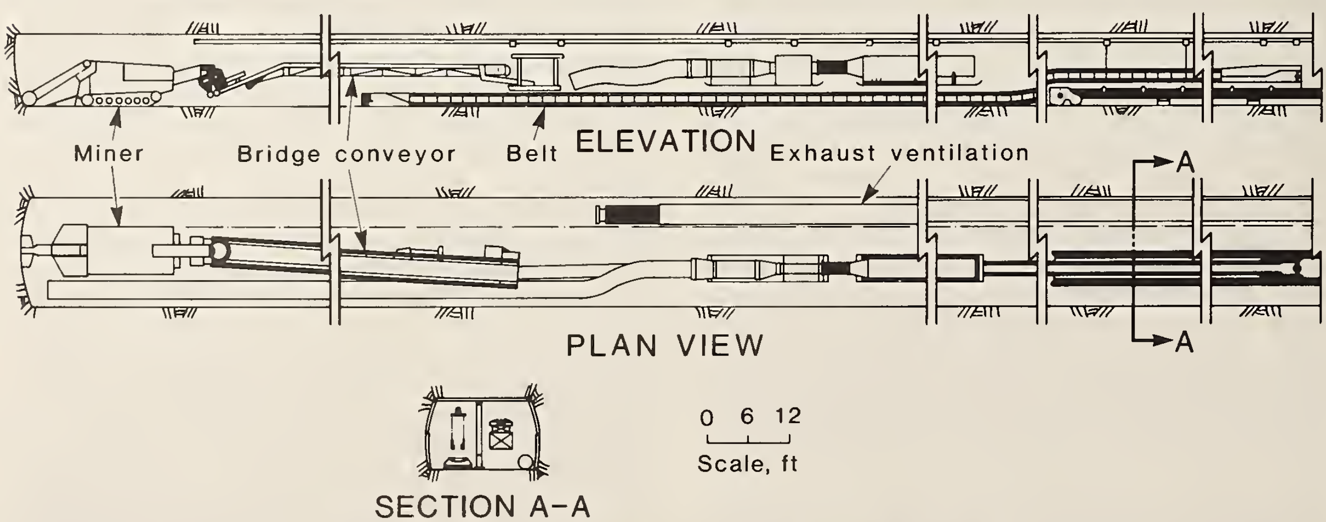

Figure 1.–Elevation and plan view of European-type single entry.

equipment from the end of one panel to the start of another (*8*).

West German engineers have persisted in their research on the optimum entry configuration for single entries. Arched entries approximately 16 to 20 ft wide and 12 to 14 ft high predominate (*6*), particularly in the Ruhr District of the Federal Republic of Germany. Supported by yielding steel arches, these entries offer good strata control as well as provide adequate clearance for ventilation requirements and for equipment needed for haulage, support, and transportation of personnel and materials. In mines with shallow depths and more favorable ground control conditions, rectangular entries are often used because support costs are less. Rectangular entries are generally lower than arched entries and are narrower at the roof than at the floor (so that they are actually a trapezoidal shape).

In the 1960's, several experiments were conducted by the West Germans using in-seam miners to develop wide (up to 30 ft), rectangular, single entries. The objectives were to (1) increase space available in the entry to accommodate larger mining equipment, (2) maximize support strength while minimizing convergence, and (3) obtain maximum support strength using at least four rows of props to divide the entry into three or more compartments (*6*). Even though the trials were conducted in what were considered to be favorable conditions, the test entries were subjected to excessive deformation caused by floor heave. This caused severe difficulties in repair and maintenance, eventually ending the experiment. The conclusion drawn was that entries with excessive width-height ratios were dangerous under the ground conditions found in European coal mines. This conclusion corroborates the experience of the first U.S. single entry, which had a cross section approximately 26 ft wide by 6 ft high. It, too, proved difficult to maintain.

Australian mine development is similar to U.S. development; that is, longwall mining is a relatively new method. It is not widely used outside of the South Coast District of New South Wales where mining conditions are considered difficult. Interest in longwall mining is growing, however, with several reasons listed by the Australian Joint Coal Board in its 34th annual report (1980-81) (*9*). These reasons included a recognition of the technological limitations of room-and-pillar mining with continuous miners, potential of increased size of mining operations using longwalls, improved coal recovery ratios, and safer working conditions.

Australian longwall panels are currently developed with continuous miners driving multiple entries. Ellalong Colliery in New South Wales was the first to experiment with single entries, driving a 14.5-ft-wide by 5.5-ft-high entry in 1981 to help overcome severe ground control problems (*10*). This field trial was considered a success; a stable roadway was developed at advance rates exceeding those produced by dintheaders used in similar conditions.

Although British mines have utilized longwalls and single entries for some time, one mine in particular used these techniques to solve a unique ground control problem. The West Yorkshire Coalfield in the Barnsley County area is considered one of the oldest industrialized coalfields in the world. As such, it is a labyrinth of worked-out seams and pillars. These pillars were left to control surface subsidence, protect underground roadways, control interaction between faces, and minimize the impact of faults within the coalbed. An estimated 100 million mt of "untouchable" coal was left underground, unminable because of the economic restraints of recovering such reserves using current technology. An additional complication is that the coalfield lies at shallow depths under a heavily populated area.

The management of the South Kirby Colliery, one of the mines in the area, decided to try a single-entry retreat longwall system to mine protective pillars while maintaining their support capabilities. Using a Dosco dintheader to drive an entry 15 ft wide by 7 ft 2 in high, an experimental panel was developed. Although several design changes were made before driving a subsequent single entry, the experiment was considered a success, with substantial increases in production and profit.

Among the benefits of using single entries for such applications are (1) the ability to mine under heavily populated areas with minimum surface damage and still maintain high productivity, (2) the ability to work seams prone to spontaneous combustion, (3) the ability to work old seams, recovering valuable reserves, and (4) the possibility of low-cost disposal of mine waste underground at the face (*11*).

VENTILATION

Ventilation practices and regulations in Europe differ from those in the United States. All, including the United States, specify that as much air as necessary be delivered to the face to dilute fumes, dust, methane (CH_4), and other gases. U.S. regulations, however, specify a minimum quantity of air for a work area per unit of time, whereas French and West German laws regulate the amount of air required per person and unit of time. Air velocities are specified in terms of maximum allowable in the Federal Republic of Germany, France, and the Soviet Union, and as minimum required in Canada, Poland, and the United Kingdom. Minimums or maximums, however, are determined largely by the function of the entry, whether a haulage route, development entry, head, or tailgate. Air velocities in the United States are specified in terms of minimum allowable for face ventilation and maximum allowable for trolley haulageways.

Permissible methane levels vary, with a maximum 1.0 pct by volume standard in all countries but Canada and the United Kingdom, which allow 1.25 pct. Allowable exemptions are given in all countries but Great Britain, with levels up to 2.0 pct (2.5 pct in Canada) return air from a bleeder system, where electrical equipment is absent, or where automatic shutoffs are present on all electrical equipment (*6*). Again, such exemptions depend on the use of the entry under consideration.

When regulations on the ventilation of longwall operations are compared, it is necessary to consider two

separate cases–developing the entry and mining the longwall panel. U.S. regulations allow permanent ventilation dividers to be used and require the installation of brattice line or similar device from the "last open crosscut" (a room-and-pillar mining phrase that defines the point where permanent ventilation controls end) to within 10 ft of the deepest penetration of the face (30 CFR 75.302-1, 1989). Auxiliary fans and tubing may be used in lieu of brattice systems; however, their use is controlled by the minimum air velocity and quantity of air required at the face (30 CFR 75.302-4, 1989). Regulations concerning interruption of the primary ventilation system and scheduled idle periods, such as weekend and idle shifts, limit the practical distance that entries can be ventilated using auxiliary ventilation. Ventilation must be provided by the primary air current from the main fan during these periods, thus auxiliary ventilation is only practical between the last open crosscut and the face, limiting its use to a distance of a few hundred feet.

European mining regulations, on the other hand, either restrict the use of permanent air dividers (as in the United Kingdom and the Soviet Union) or forbid their use entirely (France, the Federal Republic of Germany, and Poland). Development entries are ventilated instead with mandatory auxiliary systems. They may be operated over unlimited distances and may be blowing, exhausting, or combination fans connected to air ducts. Blowing-type systems generally predominate. This is very different from U.S. practice where regulations restrict the use of auxiliary ventilation systems, that is, ventilation fans and tubing, as the primary means of ventilating a working area (30 CFR 75.302-4, 1989).

One of the major differences between U.S. and European mining regulations, in regard to single-entry development, is the U.S. requirement that every working place must have at least two distinct, separately ventilated escapeways (30 CFR 75.1704, 1989). One must be in an intake air split and must not be used for belt or trolley haulage. Minimum width for this route is set at 6 ft. Because multiple entries are the rule in the United States, this requirement is usually met with no difficulty. It does, however, place a major constraint upon the use of single entries and precludes the use of European-style single entries altogether. Those single entries driven in the United States to date have complied with the law by driving one large entry and dividing it into two entries, using permanent, airtight center dividers. Escape doors were included at regular intervals in dividers.

Ventilation during the production phase of longwall mining is basically the same in Europe and the United States, with the major difference found in the way the gob is ventilated. By law, abandoned workings must be sealed in every European country that uses single entries. U.S. law, on the other hand, requires them to be ventilated using a bleeder system or to be sealed only as a last resort. No other country requires ventilation of the gob. This is because in Europe methane buildup in the gob is not considered to be a problem because of the absence of large open cavities where methane could accumulate. If the gob is not ventilated, it is argued, spontaneous combustion is impossible because of the lack of oxygen, and other sources of ignition that could set off a fire are not present. In the rare case that a methane explosion should occur, the broken rock and dirt filling the gob would act as a protective barrier and extinguish any flame before severe damage was done.

U.S. regulations require bleeder systems precisely because the large, open gob areas left when workings are mined out often become filled with gas. Bleeders are very effective in draining accumulated methane and controlling the problem of potential explosions.

In summary, longwall mining, using single entries as gate roads has become the norm in major coal-producing countries other than the United States. By late 1983, an estimated 50 pct of the world's underground coal production was attributed to longwall mining (*8*). This is because of large potential productivity gains and because of the solutions it offers to problems inherent in underground mining. These problems include the mining of deep, gassy, unstable seams and/or the economic necessity of recovering reserves previously left to control subsidence or to protect subsequent work areas. The methods used to develop, ventilate, and support these entries, and to mine longwall panels have evolved in response to the varied situations and necessities experienced. Consequently, legal requirements or restrictions in other countries have developed specifically to control single-entry longwall mining. This is in sharp contrast to U.S. regulations concerning longwalls and single entries where regulations have been extended or adapted from legislation intended for underground room-and-pillar mining.

U.S. SINGLE-ENTRY STUDIES

Two single-entry development projects were conducted in the United States during the 1970's: the Sunnyside project at Kaiser Steel Corp.'s Sunnyside No. 1 Mine in Utah and the TBM project at EACC's Federal No. 2 Mine in West Virginia. The main similarity between the two projects was that they were single-entry drivages, divided to form two compartments to comply with coal mine safety regulations concerning ventilation, location of electrical equipment, and escapeways. Other than this, the two projects were different in many respects. A description of each of these projects will help to point out their similarities and differences, as well as problems that impede single-entry development in this country.

SUNNYSIDE PROJECT

The Sunnyside project was a 9-year research study, begun in 1971, that had the objective of determining

whether a single entry supported down the center by a fire-resistant partition could be considered equal to or better than a double-entry system. The project was conducted under a cooperative agreement between Kaiser Steel Corp. and the Bureau's Spokane Research Center (SRC). Other participants included the Bureau's Denver Research Center and the U.S. Mine Safety and Health Administration (MSHA).

The Sunnyside single-entry study was originally begun in the No. 2 Mine but was moved to the No. 1 Mine when several faults and an overlying minable coal seam were discovered at the original site. Several publications describe the early phases of this experiment (*1, 12-13*), and details of the project will not be described in this report. However, a few important points should be made. The new site was adjacent to several mined-out longwall panels, including one that had just begun production when the change in location was made (fig. 2). These panels were 4,500 ft long, 500 to 600 ft wide, and had an average seam height of 6 ft. An extensive study was made of the geology of the area in conjunction with the Sunnyside experiment. This study included diamond-drilled columns from the floor and roof of nearly 20 areas where ground movements were monitored. This geological information is available in a Bureau Report of Investigations (*14*).

As originally planned, the purpose of the Sunnyside project was to study three major factors: ground control, ventilation, and safety procedures. Over 1,200 instruments were installed during the 9-year trial period. These instruments monitored roof-to-floor closure, entry deformation, and load on cribs, posts, and roof bolts, which were the primary supports used. A Bureau open-file report details the installation of the instruments and results of the monitoring efforts (*15*).

Two longwall development headings were driven in connection with the project. The first heading began in May 1973 and was driven a total of 4,500 ft. The first 1,500 ft was driven as a single entry followed by a 1,500-ft section of double entry. The final section was also completed as a single entry. This configuration allowed a good comparison to be made between single- and double-entry behavior. The single-entry sections were 6 ft high and 26 ft wide, divided down the center by a row of open wood cribs on 7-ft centers. A fireproof divider composed of steel panels coated with a fire-retardant sealant was attached to this crib line. Escape doors were installed every 100 ft to comply with regulations requiring access between escapeways. Fresh air was coursed to the working area on the left side of the divider and exhausted on the right. The conveyor belt was located in the exhaust air course, while the main supply and travel route was located in the fresh air course (*16*).

Although no major problems were encountered, the first entry took 14 months to complete, which was longer

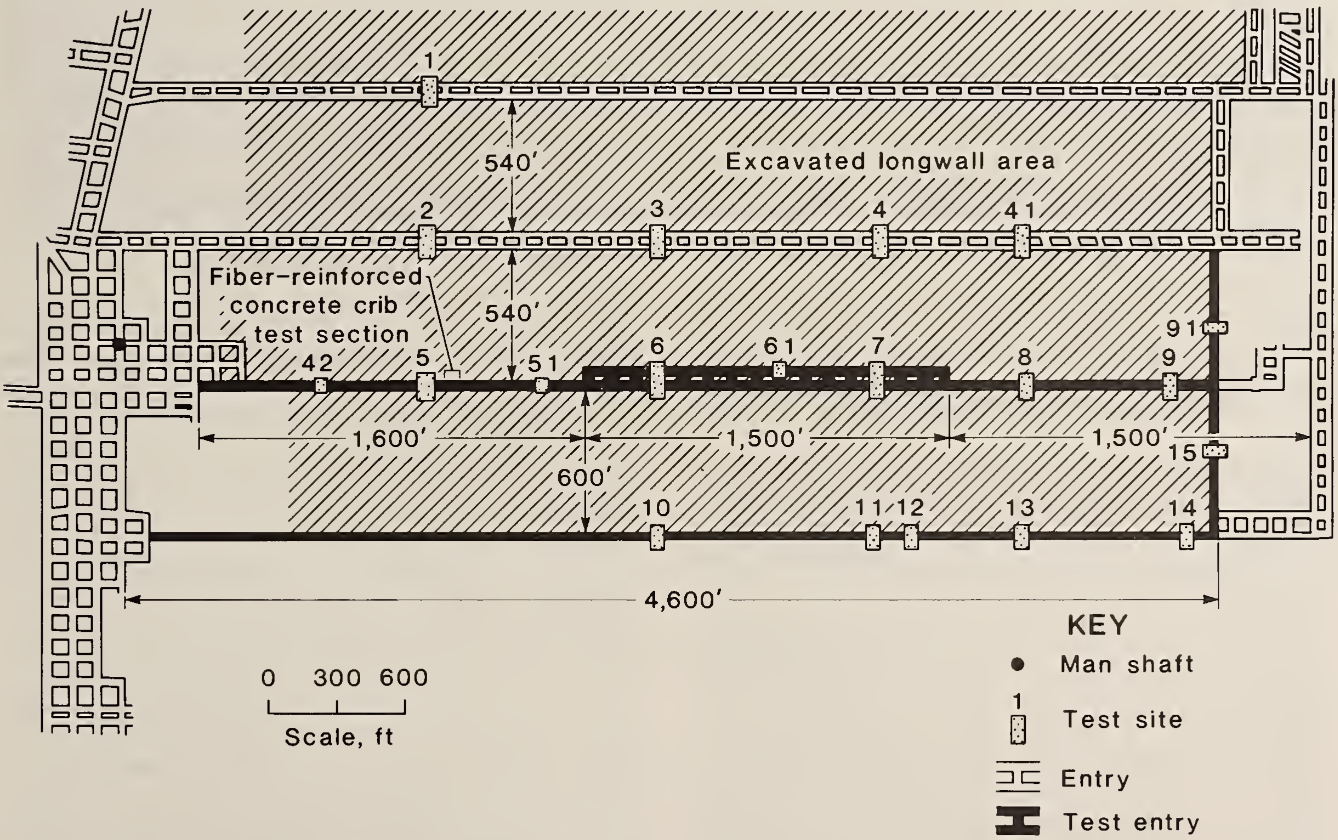

Figure 2.–Sunnyside single-entry project.

than originally anticipated. The slow progress was due to many things, including an inexperienced crew and lack of adequate working space. The original plan was to have the bolter follow closely behind the continuous miner used to drive the entry. An MSHA regulation prohibiting more than one major piece of equipment operating on the same air split made this impossible, however. Consequently, whenever the mining machine finished a cut, it was trammed out and sat idle until the bolting crew finished. This also idled the shuttle car used to transport the cut coal to the section belt and resulted in a serious waste of labor.

Another time-consuming operation was the construction of the center crib line and divider wall. A maximum of 150 ft was allowed between the permanent divider and the face, with the line brattice used to divide and ventilate this area. As the face progressed further from the main haulageway, the amount of delay due to center wall construction increased. Crib blocks, metal panels, sealant, and all other supplies, such as bolting materials and spare parts, had to be brought into the entry by battery car. This proved to be slow and inefficient. The problem was compounded by the limited space in the entry itself. Only the intake half of the entry was available for transportation, mining, and support functions. Progress was often impeded by lack of operating room.

Ventilation was another problem. Metal landing mats were used in the bolting pattern to support the roof. They spanned the entry, making it very difficult for the divider wall to create an airtight seal. The divider wall itself was the source of many leaks. As the roof converged, it tended to break the sprayed sealant away from the wall, causing air leakage, and thus became a major maintenance problem. Methane concentrations over the allowable 1.0 pct shut the section down repeatedly, requiring the crew to stop production and seal leaks, reroute brattice, or simply wait for the methane to dissipate. The use of auxiliary ventilation is required in most European mines, but is severely limited in U.S. mines in areas other than between the last open crosscut and the face. As the development face progressed further into the coal block, however, it became increasingly hard for the mine ventilation system to provide adequate air to the face, particularly in gassy areas.

Advance rates for the 1,500-ft section of double entry showed some improvement over the first single-entry section. This was attributed to the crew's familiarity with the mining method and increased working space, as well as the elimination of the center wall.

During the mining of the first longwall panel, it became obvious that the single row of wood cribs neither supported the entry adequately nor created a clean break line for the gob. Additional rows of cribs, as well as steel arches, wood posts, and steel beams, were used to maintain the entry, but in spite of the extra supports, it was often necessary to remove floor rock to provide adequate travel space. The maintenance cost to keep the entry open for use as a double gate made it obvious that the single entry, as designed, would not perform as desired. This realization brought about a redesign of the next single entry and the decision to test a new type of support.

In April 1976, a 63-ft section of fiber-reinforced concrete cribs was installed about halfway into the first single-entry section. Wooden blocking materials were used between the concrete cribs and the roof to absorb initial loads and to ensure a tight fit to the roof. The concrete crib line (fig. 3) was very successful. Not only did that section of the entry maintain its original height without extra supports, but a clean break line was observed on the gob side, with little or no punching of the cribs through the roof, as was originally feared.

The driving of the second 4,500-ft single entry was begun in September 1975 and completed in August 1976. This entry was designed to be used only as a headgate for a single longwall panel. No effort was made to hold it open to serve as a tailgate for the adjacent panel. This entry was 21 ft wide and was supported down the center by a row of wood posts on 4-ft centers (fig. 4). The usual bolting pattern supported the rest of the entry. A fire-resistant wall was constructed using metal panels attached to the posts and coated with a sealant (fig. 5). Metal escape doors were again installed every 100 ft.

Advance rates for the second single entry were higher than the average for a two-entry system, and nearly double those achieved on the first single entry. Several factors contributed to this. The crew was more experienced, the support wall was simpler and easier to install, and alignment of the entry was accomplished using a laser gun, which simplified the process. Perhaps the two major differences, however, were changes in the haulage and ventilation systems. The shuttle car was replaced by a bridge conveyor from the back of the continuous miner to a walking tailpiece at the end of the belt (fig. 6). A maximum of 120 ft could be mined before the tailpiece was advanced. Mine management estimated that this change alone improved single-entry advance rates 2.5 times (*17*).

Ventilation was augmented using two auxiliary fans and fiberglass tubing. The tubing used for intake was equipped with a flexible endpiece so that air could be directed toward problem areas. Because of this dual system, there was little time lost because of forced work stoppages caused by high methane concentrations.

A final cost comparison between the development of the Sunnyside single and double entries shows that, while advance rates were faster for a single-entry system, the overall cost was 42 pct higher than for a double-entry system (*17*). One reason for this was the higher productivity rate for double entries (there is more coal to be extracted, hence more production). The main reason, however, was that the mining cycle only allowed one operation to occur at a time. Since the union did not allow mining machine operators to also operate bolting machines, workers and their equipment sat idle at least 50 pct of each shift. When labor costs make up an estimated 57 pct of the total production costs, it is easy to see why single entries driven with cyclic systems are not competitive (*17*).

The Sunnyside single-entry project was considered a success by the Bureau in terms of reducing ground control

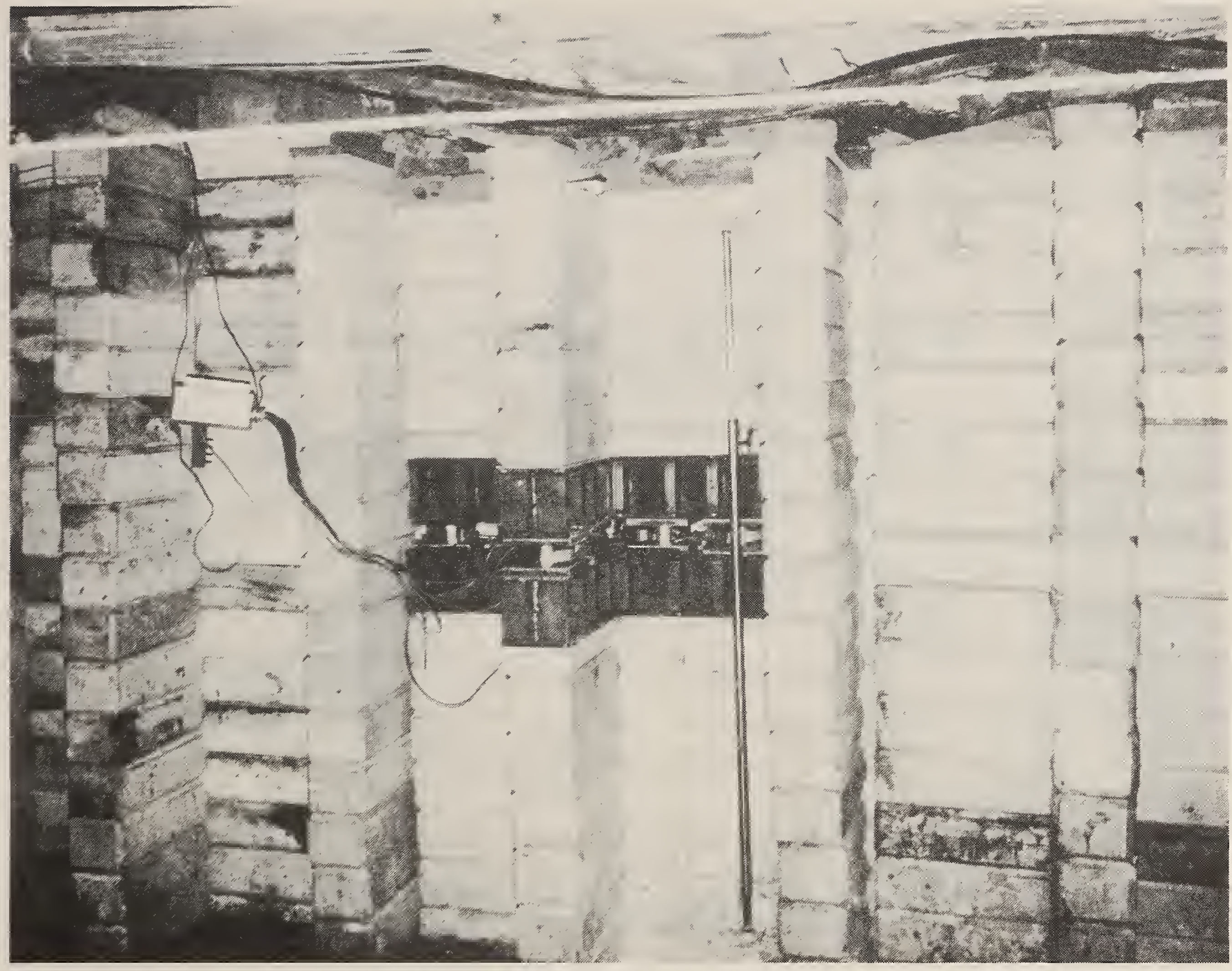

Figure 3.–Concrete crib line in 17th L single entry.

problems in deep coal mines. Many potential advantages of single entries were brought out by the trials. These advantages included reduction of bumps by eliminating chain pillars and decreasing the number of openings, faster development rates, elimination of problems caused by pillar remnants, extraction rates for panels approaching 100 pct, reduction of methane emission from exposed ribs, and simplification of mining procedures due to straight-line development with no intersections. The major disadvantages listed by the Sunnyside Mine management were losses in productivity, increased costs to maintain the single entry as a tailgate, and the possibility that the center wall would fail to provide a smoke-free escapeway should a fire occur on the belt or equipment (*17*).

An important point that should be noted when judging the success of the project is the marked improvement in the construction of the second single entry. Design changes necessitated by failures in the first panel development were successful in eliminating many of the early problems. This demonstrates the evolutionary process that will be necessary for the successful implementation of single-entry systems in the United States.

TUNNEL–BORING MACHINE PROJECT

The TBM project was proposed in 1971 by EACC. Its purpose was to test the technical and economic feasibility of developing coal mines with TBM's. The eventual demonstration was cosponsored by EACC and the Bureau's High Speed Coal-Mine Development Sub-Systems program. SRC served as principal investigator for the full term of the project, from 1974 to 1979, even though the program was transferred to DOE in 1977.

The concept of using a TBM for driving development headings is a departure from the traditional U.S. development strategy discussed earlier with regard to European development methods. The TBM concept follows the European strategy of developing a coal property from its center outward to its boundaries and then mining inward, leaving the mined-out areas behind. Mined-out

Figure 4.–Single-entry center wall in 18th L, right side.

Figure 5.–Single-entry center wall in 18th L, left side.

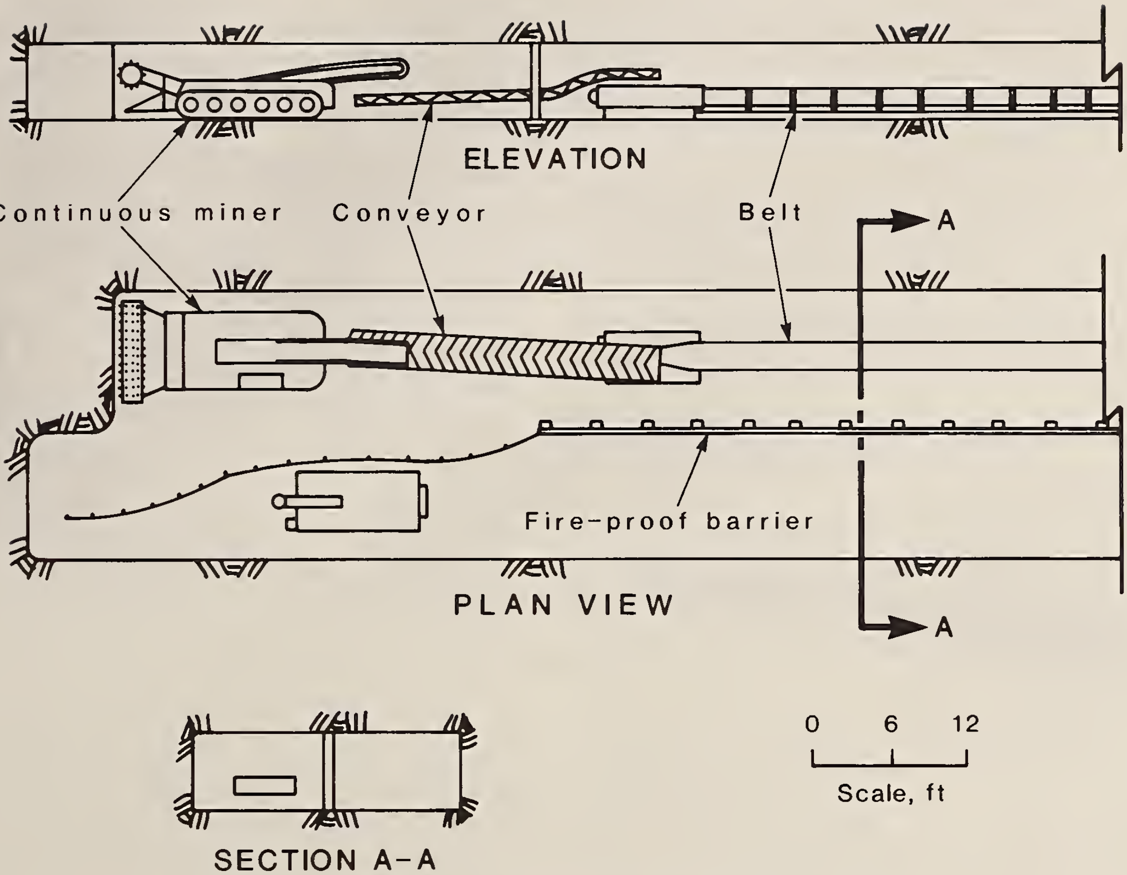

Figure 6.–Elevation and plan view of Sunnyside split single entry.

areas are abandoned, so very little coal must be left in place for support. Maintenance of development headings is minimized because little ground is disturbed during development, and once an area has been mined out, the development headings may also be abandoned. This strategy is, of course, in conflict with present U.S. regulations regarding gob ventilation; however, its advantages cannot be overlooked, that is, rapid development, improved extraction ratio, improved subsidence control, and improved ground control. This strategy also allows flexibility in product control and, in gaseous mines, the degasification of the coal prior to mining (*18*).

The site selected for the project was the Northeast Mains area of EACC's Federal No. 2 property where earlier attempts at conventional development had failed. Development of a 10-entry heading had been halted in the area some years before because of excessive methane. Although the high concentrations of methane presented special problems, successful implementation would prove that single entries could be driven in extremely gassy coal.

At the time of the project, McGuire Corp. of Fort Smith, AR, operated the only permissible TBM in the country. The machine had been used to drive slopes down to coal seams and could be modified to drive in coal without going through the lengthy approval procedures required for new machines. McGuire was subcontracted by EACC, and preparation for the project began in 1974. The TBM was modified to excavate an 18-ft-diam tunnel a distance of 6,000 ft to intersect a shaft constructed for the project.

The assembled TBM system was relatively complex for a coal mining operation (fig. 7). The basic machine consisted of a primary unit and a secondary unit. The primary unit included the cutterhead, loading buckets, roof bolters, and hydraulic gripping rams (wall grippers). The secondary unit provided the electric and hydraulic power for the TBM system. The combined units were 50 ft long and weighed about 35 st. Immediately behind the secondary unit, a 50-ft skid-mounted trailing unit (tertiary unit) was used to provide the following support functions: (1) track installation, (2) application of shotcrete, and (3) divider support beam installation. The trailing unit was equipped with a monorail and air-powered cranes to handle heavy equipment and materials.

The primary, secondary, and trailing units included steel panels dividing the tunnel entry into upper and lower compartments (fig. 8). Steel divider panels also trailed these units for a distance of 320 ft to an automatic mine-car loading station. These sliding steel dividers carried the primary haulage system—an extendable conveyor formed by

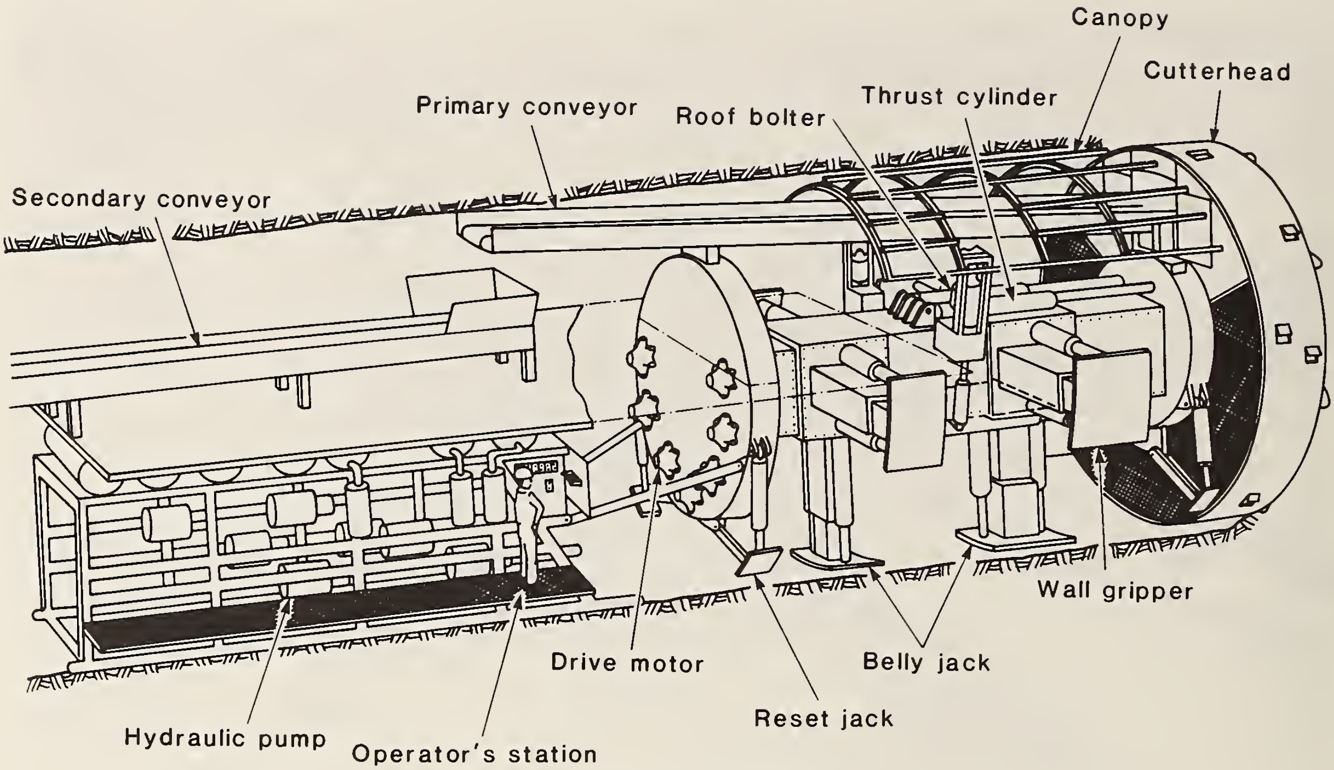

Figure 7.–Tunnel-boring machine.

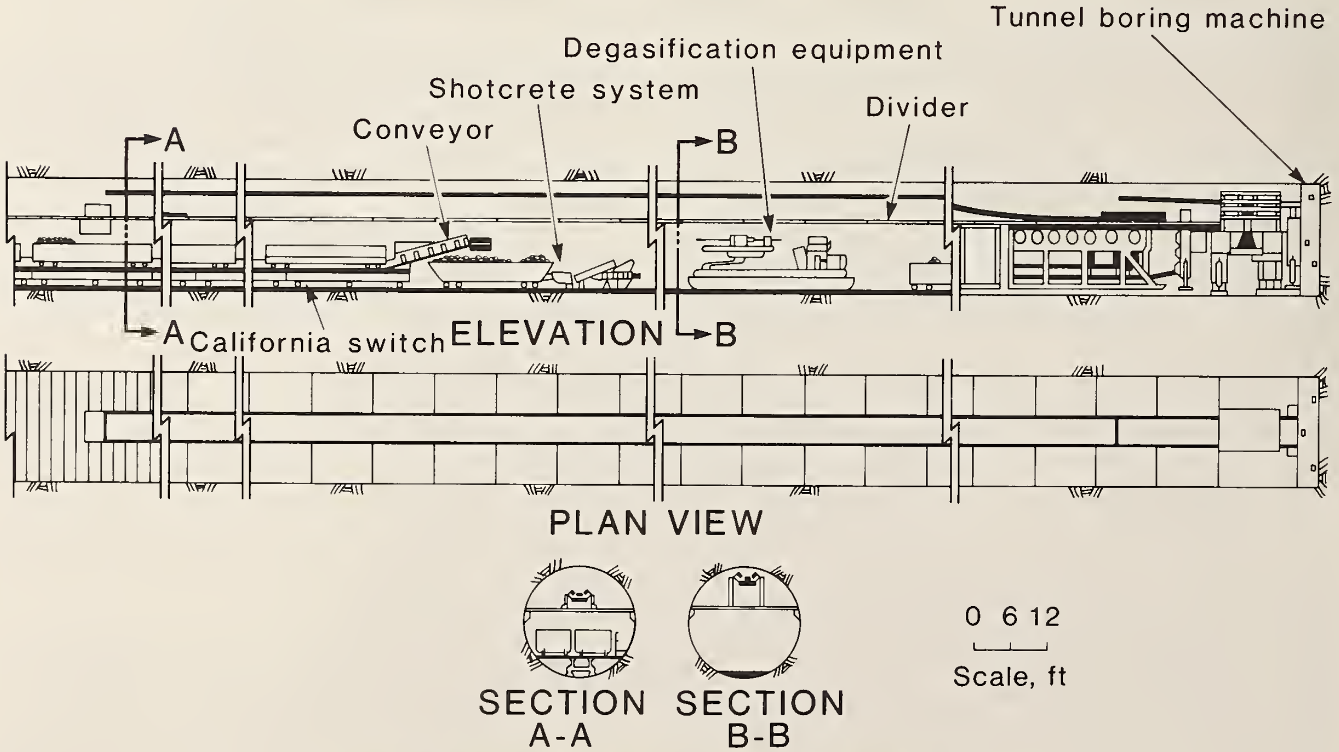

Figure 8.–Elevation and plan view of TBM split single entry.

two belts. Permanent concrete panels, called flexicore, were installed beneath a raised portion of the temporary divider just ahead of the loading station. Together, the sliding steel and the flexicore provided a continuous, horizontal divider from the entrance of the tunnel to the face. Ventilation air was directed through the lower compartment to the face and exhausted through the upper compartment. Ten-ton mine cars were loaded at the loading station on a specially designed double-track carriage called a California switch. This unit was 390 ft long with a 40-ft ramp up from the main track. The California switch followed the TBM as it advanced by riding on the main track. The entire TBM system was approximately 790 ft long when fully extended, but could collapse to about 540 ft when the loading chute and California switch were moved up. This was done at approximately 250-ft intervals.

The TBM was a system designed to excavate, support, and construct the tunnel in one continuous operation. Additional support operations were carried out between the trailing unit and the front end of the California switch. Within this area, service lines were installed, degasification holes were drilled, and a 3-in layer of shotcrete was applied to the walls. Two roof bolting machines located on the primary unit provided all the immediate roof support that was necessary. Installation of the flexicore divider took place from atop the California switch, beneath a raised portion of the sliding steel divider. It was anticipated that such a system would be capable of 100 ft of advance per day, as had been accomplished with TBM systems used on civil engineering projects. Actual advance rates, however, were much lower because of a number of operational, design, and labor problems.

Boring began in January 1976 with only the primary and secondary units in operation. As the TBM advanced, the trailings sections of the system were added until the entire system was assembled. Boring with the complete system did not begin until January 1977. The length of time taken to assemble the total system was a reflection of the problems incurred in making the system comply with mining regulations.

The final contract report concerning the TBM project (*18*) gives an account of the problems associated with the project from start to finish. Many of these problems were associated with equipment design or failure and with labor or management issues. The major concerns, however, involved the single-entry aspects of the project. Fire prevention is essential in any single entry, raising questions of electrical permissibility. In Europe, <u>all</u> equipment within a single entry must be permissible. This was the primary difference between European regulations and U.S. practices concerning equipment. Other differences were influenced either directly or indirectly by the determination of where permissible equipment would be allowed. In both the Sunnyside and the TBM projects, the last open crosscut was generally determined by MSHA to be the end of the permanent dividers. In the case of the TBM project, however, a decision was made not to allow nonpermissible equipment within the mouth of the tunnel. This effectively made the tunnel mouth the last open crosscut. The one exception to this rule was the use of nonpermissible battery-powered locomotives in the tunnel behind the end of the permanent dividers. This allowance was granted by MSHA because no permissible locomotives were available and their construction would have been very costly and would have delayed the project by many months.

The decision to use only permissible equipment in the tunnel affected another critical area. Because of the length of the entry, the operating voltage (480 V) could not be carried to the machine by a cable of practical size. It was necessary to use a transformer on the secondary unit to reduce the primary mine voltage of 7,200 V to 480 V. Permissible transformers are not uncommon, but one using 7,200-V, 1,000-kV•A primary power had never been built. In addition, 30 CFR 18.47 (d) (5) implies that face voltage shall not exceed 4,160 V. During the initial boring phase, a 480-V trailing cable was used while boring the 725-ft length required to assemble the complete system. Concurrently, a variance was sought under 30 CFR 18.47 (d) (6), which allows MSHA to approve high-voltage equipment, provided additional safeguards are met. Many delays occurred during the approval process. Initial testing of a 7,200- to 480-V transformer at the Westinghouse High Power Laboratory in Pittsburgh, PA, led to improvements and eventual approval.

Equipment permissibility is, of course, required in underground coal mines because of the explosive atmosphere created by the generation of coal dust and the liberation of methane. In addition to permissibility, the amount of dust and methane in the ventilating air was also strictly regulated. The Northeast Mains area at the Federal No. 2 Mine had an established history of producing excessive methane. That area of the mine had already been involved in a degasification project with the Bureau's Pittsburgh Research Center, so a degasification plan was devised to incorporate the tunnel into the existing system. The plan was to drill holes angled into the coal ahead of the tunnel face and vent the methane through a 6-in pipeline and a borehole to the surface. These 3.5-in holes were drilled into alternating ribs at 250-ft intervals as soon as the trailing unit had passed and were angled 20° from the tunnel centerline to place them ahead of the face.

Many problems were encountered with the degasification system and it was eventually abandoned. As in the Sunnyside project, auxiliary face ventilation was used to control methane liberated during excavation. Several "hot spots" were encountered in the tunnel that halted work until the methane level was reduced, particularly toward the end of the project when advance rates were high. The most important control measure used, however, was applying shotcrete to the tunnel walls, which sealed the coal from the atmosphere and prevented contamination of the intake air before it reached the face. Methane liberation in gaseous coal mines will always present a special problem in single entries and will require that some type of sealant be used or that other measures be taken.

Another ventilation problem common to both the Sunnyside and the TBM projects was leaks in the divider between the intake and return airways. Because of the experimental nature of the TBM project, MSHA required that 50,000 cfm of intake air be supplied to a control point behind the trailing unit. Early in the project, it was recognized that maintaining this airflow would be a problem, and a detailed ventilation study was begun (*19*). The study concluded that there would be sufficient airflow to complete the tunnel only if leaks in the divider could be controlled. The major sources of the leaks were cracks between the members of the permanent dividers and poor seals around air-lock doors in the dividers. Leaks were sealed on a continual basis throughout the project, but even so, only 50 pct of the air entering the single entry actually reached the face. This is considered a major obstacle to this type of single-entry arrangement. If multicompartment single entries are to be used, improvements in methods of sealing divider walls will be necessary.

Another major obstacle to the TBM project was the divider wall construction. As discussed earlier, the split single entry was developed as a means of driving a single entry while at the same time complying with the CFR and State mining laws concerning separate escapeways from each working area. For a divider wall to serve as a substitute for a line of chain pillars and stoppings, it has to prevent a fire or explosion on either side of the divider from propagating to the other side (30 CFR 75.329-2). This meant that the divider wall had to be built from substantial materials. The divider wall was also required to have doors spaced every 100 ft to allow workers to pass from one side to the other. Most of the doors were 2 by 2 ft, but every fifth door was much larger and had a stairway that would allow an injured worker to be carried through on a stretcher (fig. 9).

An industrial engineering study conducted for the Bureau identified the installation of the divider wall as the most time-consuming task in overall tunnel construction. Therefore, the divider wall not only created problems with ventilation, but its construction would have controlled the TBM excavation rate had it not been for many other unscheduled delays. During the Sunnyside project, the divider wall created ventilation problems and its construction was a major obstacle to rapid development of the entry, particularly because of the difficulties encountered while bringing construction supplies in, but also because of the

Figure 9.–Lower compartment of entry developed by TBM.

time used to build the wall, during which no mining occurred. Experience gathered from both projects has shown that divider wall construction and maintenance will be major obstacles to the efficient driving of split single entries.

The single-entry projects in the United States have provided valuable experience to the mining industry. The most obvious lesson was that in order to bring European single entries into compliance with U.S. law, changes were made that created problems in construction and ventilation. These problems muted the primary reasons for single-entry development, that is, improved ground control, rapid development, and greater overall safety under severe mining conditions.

OTHER SINGLE-ENTRY RESEARCH STUDIES IN UNITED STATES

Two other studies initiated by the Bureau have contributed significantly to single-entry research in this country. The first of these studies was conducted by NAMCO and resulted in a report entitled "Single-Entry Longwall Study" (*6*). The second was a study of the design of a single-entry development system for retreat longwall mining systems, conducted by Ketron. These and several other related studies will be discussed briefly in the following sections.

NORTH AMERICAN MINING CONSULTANTS STUDY

The purposes of the NAMCO study were threefold: first, to identify State and Federal regulations that constrain driving longwall development panels; second, to propose optional single-entry layouts and mine designs; and third, to compare costs between the proposed designs and conventional panel development.

This study concluded that true single-entry developments are prohibited by current regulations. Under 30 CFR 75.1704 and 30 CFR 75.1704-1 (1989), every active workplace is required to have two separate escapeways, one of which must be located in intake air. The laws of several states as well as 30 CFR 75.302 (1989) control the use of auxiliary ventilation systems and limit their use to the working face. Since 1970, 30 CFR 75.326 (1989) has prohibited the use of belt conveyors in intake or return air passages, limiting their installation to separate compartments carrying reduced airflows. Two other regulations, 30 CFR 75.316-2 and 30 CFR 75.311 (1989), restrict the use of single entries for longwall panel development by requiring bleeder systems for mined panels and by prohibiting any intake air containing more than 0.25 pct methane from passing a gob area if it is to be used to ventilate an active working face. For both the Sunnyside and TBM projects, regulations prohibiting the installation of belt conveyors in return air were waived under a grandfather clause, and the separate ventilation and escapeway requirements were met with the split-entry arrangement.

The NAMCO study also compared the mining laws of the United States with those of other countries, highlighting the relative merits of each. Three longwall panel development systems were compared: a multiple-entry system, a European-type single-entry system, and a modified system of NAMCO's own design that was a compromise between European practices and U.S. requirements. The modified system failed to satisfy all U.S. regulations, but it was similar to the modified single entries driven at Sunnyside. This study concluded that in the absence of adverse geological conditions, the multiple-entry systems required by U.S. laws and regulations are inherently safer than single-entry systems. The study also noted that where the physical conditions become hazardous for the multiple-entry method of working, those U.S. laws and regulations that constrain or prohibit European-type single-entry workings negate their purpose and are of doubtful benefit. In such cases, European regulations, methods, and experience, which are drawn directly from more hazardous conditions, offer a method of single-entry operation that provides improved control over the strata and greater overall safety (*6*).

NAMCO's economic comparison also favored the multiple-entry system when used in conventionally developed mines. A case was made, however, for the economic benefits of single-entry development for an entire mine property. The central argument was that increased resource recovery could offset the higher capital cost of single entries.

KETRON STUDY

The purpose of the Ketron study was to analyze the single-entry demonstrations conducted in the 1970's and to design an improved, legally acceptable single-entry system for developing retreat longwall panels. The resulting concept was another modified system based on an entry split into three separate compartments: an intake airway, a return airway, and a belt compartment in the center of the entry. The proposed system would be similar to a three-entry room-and-pillar system and thus would comply with current regulations, provided favorable interpretations concerning the divider walls were applied. This system would meet those regulations that presently constrain or prohibit driving two-compartment, split single entries, as well as true single entries. The regulations dealing with bleeders and fresh air could also be met with this configuration.

The Ketron design recommended a class of European continuous mining systems generally referred to as "partial cutting machines" and specified the Eickhoff short-face ranging shearer as the best alternative. This system is an advancing "mini-longwall" system with a standard longwall shearer riding an armored face conveyor. A stage loader feeds a belt conveyor, providing continuous haulage. This system can drive a single entry between 20 to 40 ft wide. Roof bolters are mounted on the mining machine for immediate support. The Ketron design called for a 30-ft-wide entry. Additional support for this span would come

from two divider walls constructed to form a three-compartment system. The key to supporting such a wide span would be to prevent as much roof convergence as possible before installation of the support walls. The Eickhoff system would allow the walls to be constructed to within 12 ft of the cutting face.

The primary advantages of the Ketron entry design would be in meeting the regulatory requirements and in providing a truly continuous mining system. As long as the divider walls were interpreted as adequate substitutes for chain pillars and stoppings, regulations would be the same as for three-entry systems. The delays and loss of productivity associated with the Sunnyside single entry would be superseded by the total system approach provided by the Eickhoff continuous miner. The apparent disadvantages are that two divider walls must be constructed and sealed and that these walls must be strong enough to support a 30-ft span. Several wall designs were evaluated in the study. The most desirable design consisted of a yielding steel post for support, wire mesh for lagging, and fiber-reinforced resin as a sealant. Based on the TBM and Sunnyside projects, the construction and maintenance of these walls would be an impediment to rapid, efficient driving of this type of entry system. The concept delivered by the Ketron study is, however, a significant improvement over past U.S. single-entry systems. Questions remain to be answered, particularly with regard to the support of a 30-ft roof span, the construction of the divider walls, and MSHA's interpretation of regulations concerning the split single entries. Many of these questions could be answered only by carrying out a field demonstration similar to the Sunnyside and TBM projects.

RESEARCH RELATED TO SINGLE ENTRIES

During the 1970's, there were many additional studies undertaken in support of single-entry research or to investigate related subjects. Many of these studies dealt with new types of instruments such as the Creare vibrating-wire stress gauge (*20*) or with new equipment such as the Dosco in-seam miner (*21-22*). Other studies, funded under contract by the Bureau, produced computerized two-dimensional (*23*) or three-dimensional, finite-element analyses of the Sunnyside single entry, based upon the data obtained during the trial. One finite-element analysis compared the theoretical stability of several different entry configurations, including the single entry (*24*).

Another Bureau study using the single-entry concept at Sunnyside involved installing a flexible steel liner in an advancing tailgate and monitoring it from November 1976 to March 1977. The liner provided a temporary second escapeway and return air conduit for the 15th R longwall panel. It was made up of 4-ft-diam, 4-ga steel sections bolted together and installed immediately behind the second longwall support, which was a combination of chocks and shield supports. An inert cushion was used as a base for the liner, which was usually buried 2 ft in the bottom. The first 50 ft were protected by a double row of wood cribs, but thereafter the liner's only protection came from wood posts and broken rock hand shoveled over it. Six stations were monitored in the 992-ft liner to measure deformation. As a result of information gained during this study, the Bureau funded a contract to design and demonstrate a more permanent liner (*25*).

Another aspect investigated was divider-support walls. Initially, different materials for construction of divider walls were evaluated (*26*), and later a rapid center wall placement system was designed using foam concrete as the construction material (*27*). There were also investigations into the economic and safety aspects of divider wall systems (*28*). Divider wall research led to a Bureau project to design and test concrete cribs. These concrete crib blocks not only proved to be much better supports than their wooden counterparts, but they also were lighter, cheaper, and easier to install (*29*). Field tests of two crib block configurations were held in conjunction with the Sunnyside project, and two more designs were tested at five other U.S. mines (*30*). As a result of that research, concrete crib blocks are being manufactured commercially and are being used more often underground.

Many other projects not directly related to single-entry research were associated with the Sunnyside and TBM demonstrations. These demonstrations merely provided convenient in-mine laboratories for investigating new hardware and mining concepts.

CONCLUSIONS

The four projects described in this report–the Sunnyside project, the TBM project, the NAMCO study, and the Ketron single-entry design–have had a great impact on single-entry research in this country. The Sunnyside and TBM demonstrations were different in purpose and design; however, they established the compartmentalized entry as the U.S. answer to the single entry. Although the NAMCO study raises some serious questions about the effectiveness and relative safety of this type of system, both the NAMCO study and Ketron design used this basic concept in their proposals for future single entries. The divided single-entry concept was not selected for its simplicity or its efficiency, nor was it selected because of improved ground control or safety. It was selected because it is more easily adapted to U.S. mining regulations.

Divided single entries have been driven and used without mishap, but their productivity and economics have not been attractive. Difficulties have arisen in adapting single entries to U.S. mining laws. Mining regulations, both State and Federal, have evolved over the years to govern room-and-pillar mining and limit the introduction of new and different mining methods. Single entries, for example,

were possible only after obtaining variances from statutes regarding permissibility and by liberal interpretation of regulations dealing with ventilation seals and fire barriers.

In the United States, ventilation and escapeway regulations have forced the use of a divider wall. For a divider wall to be in compliance with mining law, however, it must not allow the propagation of either a fire or an explosion from one side to the other. The Sunnyside and TBM projects set the precedent for entry development using a divided single entry. For longwall panel development, where the most critical need exists, the Sunnyside project demonstrated that, although the entries were successfully driven and used, the more conventional two-entry system was preferable. Construction and maintenance of the divider wall and lost productivity caused by cycling equipment at the face made these entries too costly.

The Ketron design is indicative of the next generation of divided single entries, and while a systems approach to the design has eliminated delays caused by rotating workers and equipment at the face, the three-compartment concept requires doubling the construction time and widening the entry span. This three-compartment design will be necessary to comply with current U.S. regulations in all coal mines except those where grandfather clauses permit the operation of conveyors in return airways. In addition to these unsolved problems, a major safety question is at issue with the divided single entry: Are divider walls actually barriers to fire and explosion as is mandated by 30 CFR 75.329-2 (1989)?

Single-entry development in the United States is far from perfected. Many problems remain unsolved, such as how to control excessive amounts of methane in gassy areas. Experiences to date have demonstrated that the problems are not insurmountable, however, and that they can be solved by ingenuity and careful engineering. The pertinent questions for now concern the future of the single entry in this country. Is there a need for this method right now? Will there be a need for it in the future? The general consensus of nearly all the single-entry investigators is that although the economics and efficiency of the modified U.S. single entry are not attractive, they do provide additional stability in deep mines. Kaiser Steel Corporation management said in assessing the Sunnyside experiments (*17*): "It has been proved that a single entry can be driven in less time with no diminution of safety to the face crew. Future mining, under deeper cover and less competent roof, could easily swing the tide of opinion toward the single-entry concept."

If single-entry technology is needed, what direction should it take? One direction leads to further development of the divided single entry in order to comply with Federal and State regulations regarding ventilation and escapeways. The other direction leads to the adoption of European technology and its attendant regulations.

Further development and refinement will surely be necessary to make divided single entries meet current mining regulations and be economically attractive. European single-entry systems will not comply with U.S. regulations; however, years of experience with these systems have proven them to be safe and efficient longwall development techniques under European conditions. In the end, the future of single entries in this country will be decided by industry needs and further reconciliation of regulatory concerns and the technical and economic merits of single-entry systems.

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